

An Open Interactive Survey Platform to Collect and Analyse Users' Privacy Decisions in Pervasive Computing Environments

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Abstract— One of the critical barriers of applying pervasive computing technologies to real-world environments is the privacy risk of transmitting and sharing personal information of users across computing entities. Several studies have collected and analysed users' privacy concerns in PCE, but most suggest only privacy policy models which do not consider the actual PCE. Moreover, there is no relationship between these works and ongoing research, as there is no common survey model that can verify a given privacy policy using the actual privacy decisions of users. In this paper, we propose an open interactive survey platform (OISP) that provides a virtual PCE. Through this survey platform, we can obtain users' actual privacy decisions and open the results. The method is simple and reusable because a survey scenario can be based on a video clip from a third party and shared with other researchers. In addition, a privacy model can be verified by comparing it with other models through the results of previous surveys. In this paper, we describe the architecture and flows of the proposed survey platform and show that the proposed survey is 28% better at reflecting users' privacy decisions than the existing paper-based survey method.

Keywords—pervasive computing environment; privacy; interactive survey

I. INTRODUCTION

In pervasive computing environments (PCE), various devices dynamically connect to each other and communicate frequently. From the viewpoint of individual users, their devices also connect and communicate with other devices frequently. In addition, by providing personal information, a user can be served with rich and more effective personalized services from service providers. However, because connections and communication require the user's implicit/explicit privacy decisions (e.g. approval, refusal, negotiation) each time, it becomes troublesome for the user in terms of security and convenience. Moreover, some personal information can be exposed, collected and exploited in a manner different from users' intentions [1].

Many studies have sought to ensure the privacy of users in PCEs. However, these privacy models were not verified in

terms whether they are suitable to represent the actual privacy decisions of the user. Although some surveys and implementations were accomplished, it is difficult to validate the results because they do not provide sufficient details about the survey, such as the environment, implementations, and question-answer pairs. In addition, the experimenter cannot convince that their bias did not affect the results at all.

To solve these problems, we need a survey method with which we can collect users' actual privacy decisions while sending their personal information to another party in the PCE. In addition, the survey method should be open to other researchers so they can reproduce an earlier survey and even utilize the results of earlier surveys. Then, by the survey method, the researchers should be able to compare and verify the performance of a privacy model. The survey method should also be easy to use but should exclude experimenter bias.

In this paper, we propose an open interactive survey platform (OISP) that allows a user to experience a virtual PCE. While the survey participants experience a virtual PCE by watching future-prediction video clips made by major corporations, the survey platform can collect the privacy decisions of the participants with its interactive feature. For a better user experience, the survey platform interacts with the mobile device of the participant. The survey platform is not dependent on specific device specifications, as we developed the survey platform based on common web technology. In the survey platform, the environment and the result of a survey can be shared with other researchers. Moreover, it is easy to add a new survey consisting of a scenario and some questionnaires. In this paper, we explain the architecture and the flows of the survey platform. In addition, we show that the proposed interactive survey is 28% better at reflecting users' privacy decisions than the existing paper-based survey method.

The contributions of the proposed method are as follows. First, it is able to collect the actual privacy patterns of users. In the survey platform, users can become immersed in a survey by watching a video clip and interacting via their mobile devices. Second, it is possible to verify a privacy model objectively. Because the survey platform can share a

survey and the results, we can reproduce the existing survey or compare the performance levels of different privacy models using the existing results. Third, because the survey method is online, the experimenters and participants do not need to consider to the place, time, or implementation details of their survey. Fourth, the survey platform is flexible when seeking to add a new survey. Thus, it is possible to analyze a privacy model from a variety of perspectives.

This paper is organized as follows. Chapter 2 shows related works and their limitations. Chapter 3 describes the requirements of the survey platform for a privacy model in a PCE. Chapter 4 proposes an open interactive survey platform and explains its architecture, flow, and characteristics. Chapter 5 shows the implementation details and chapter 6 gives a comparative analysis using several surveys. We discuss the proposed platform in chapter 7. Lastly, we conclude and present future works in chapter 8.

II. RELATED WORKS

Zhu et al. [2] holded that it is not clear whether people are aware of the importance and sensitivity of various types of identity information and how their specific concerns about identity exposure and privacy are related to actions that they have undertaken. Their paper-based surveys to collect users' concerns and actions show that these two features are not in fact related each other. According to their study, this occurs because a user tends to be more conservative in their responses when the user participates in a privacy survey. Although users report that they are cautious about security and privacy, their actual behaviors in the survey environments show this is not always the case. This implies that the traditional (e.g., a paper-based implementation) survey method may not effective for collecting the privacy decisions of users.

Olson et al. [3] [4] derived users' privacy preferences and the deviation in these preferences by investigating how and if users provide personal information to others. However, there research was limited to presenting the tendency of a user's privacy behavior. Moreover, there was no follow-up study. Because their survey lasted for more than two hours, it the survey was difficult for users, which could confound the results. Although the details were not explained, if the survey was not well designed, subjective answers could be given. This inconsistency may affect the privacy criteria of the user. Therefore, the results may not reflect the user's behaviors accurately.

Most existing studies on privacy in PCEs lack a concrete evaluation of their privacy models. Because we could not verify these models in an actual PCE, we do not know whether the model is correct. We need to check that they can identify a user's actual privacy decisions and represent a privacy model for a PCE.

A few studies actually implemented their models in a specific environment and tested it with several participants. However, a number of problems arose. First, the details of their survey methods and experimental environments were not publicly disclosed. Due to this limitation, other experimenters

could not perform the survey in the same way. Second, in order to develop a real survey environment, an experimenter has to pay close attention for the place and the implementation. Most studies did not have enough resources; therefore, the model and results were presented at the concept level. Third, an experimenter has difficulty using the survey environments of other researches. Although an experimenter feels free to share their survey environments, this geological difference makes it difficult to perform a survey with different participants. It is also difficult to share the results of past surveys with other researchers. Therefore, a privacy model cannot be compared to another privacy model using the same input data. Fourth, an experimenter may design a survey scenario and questions of the survey while reflecting his/her intentions. A biased survey cannot be verified objectively by the others.

III. REQUIREMENTS

A survey method that overcomes the limitations noted in the previous section must satisfy the following requirements. First, it should collect the users' actual privacy decisions in a PCE. Otherwise, we cannot identify whether a privacy modeling for PCE works correctly or not. Because it is difficult to express an actual PCE properly, the survey method should provide as much information about the PCE user experience as possible.

Second, an experimenter should be able to reproduce a survey or reuse the results of previous surveys easily. Because the survey results can be influenced by the inclination of the participants, the survey method should provide a way to perform a previous survey with other participants who have different characteristics. By utilizing the results of previous surveys, moreover, an experimenter can compare the performances among several privacy models.

Third, the survey method should be easy to use. From the viewpoint of the experimenters, they can initiate a survey with a simple task. Also, the survey method must reduce the burden of time and space when participants perform the survey.

Fourth, the survey method should use a scenario that is not biased by the experimenter's subjectivity. The survey method can present several scenarios from a third party to enhance its objectivity.

IV. AN ONLINE INTERACTIVE SURVEY PLATFORM

A. Survey Platform Architecture

In this paper, we propose an open interactive survey platform (OISP) for privacy modelling in a PCE. As an open platform, it freely allows the registering and performance of a survey. It allows users to take advantage of the survey results in many ways. Moreover, because it provides a realistic user experience through interaction with a user, the proposed survey method can assess the user's privacy decisions more accurately. Figure 1 shows the overall architecture.

The object 'experimenter' requests a survey and the object 'participant' performs the survey through the survey platform. The experimenter can register and request a survey that may target specific participants. He/she can execute another

existing survey and view the results of the post-executed survey. The participant can join in the survey currently being performed. To provide an interactive experience to a participant, the proposed survey method maps the participant's devices (e.g., a personal computer (PC) or a mobile device). While watching a survey's contents on the PC, the participant responds as regards their privacy decisions when a service provider requires the participant's personal information to offer a personalized service.

The survey platform consists of modules and databases for the experimenters and participants. First, we describe the modules. The first modules are related to the requirement of providing a good user experience in a PCE. The last three modules are related to the requirement of providing an easy and non-biased survey.

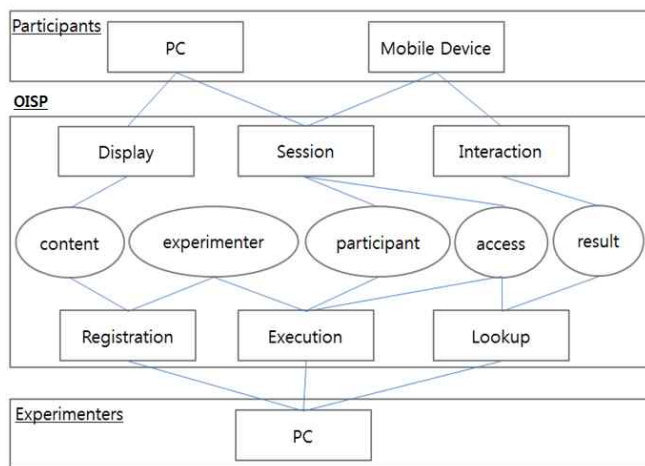


Figure 1. The architecture of the proposed survey platform

- **Survey Display Module:** This shows the content of a survey via the participants' PC.
- **Session Management Module:** This maintains the mapping between the PC and the mobile device of a participant.
- **Survey Interaction Module:** This sends several questions about the participants' privacy decisions and then receives the results from the participants' mobile devices.
- **Survey Registration Module:** This helps an experimenter to upload their survey to the survey platform.
- **Survey Execution Module:** This allows an experimenter to run one of the surveys provided in the survey platform with specific participants.
- **Survey Lookup Module:** This provides a survey's result, which includes the survey's details and the answers of the participants.

The databases located on the survey platform are as follows.

- **Survey Content DB:** For each survey, this has a list of video clips, captions, sub-captions and questions. The question has a statement and several answer options. The video clip shows a scenario related to the question.

With the video clip, the captions explain the meaning of the scenario clearly. The sub-caption guides what the participant has to do with their mobile device for the question.

- **Survey Experimenter DB:** This is a list of experimenters who can register, execute, and lookup a survey.
- **Survey Participant DB:** This is a list of participants who can perform a survey.
- **Survey Access Control DB:** This maintains a mapping table that shows which participants can perform the survey and which experimenters can share the results of the survey.
- **Survey Result DB:** For each survey, this stores the participant's responses to the questions in the survey.

B. Survey Process

In this section, we show the flow of a survey in terms of the participants and the survey platform. We assume that each participant was invited to the survey by an experimenter and that the participant was provided a link to the survey platform.

1. A participant accesses the survey via their PC. When the participant submits their identifier (e.g., by email), the survey platform checks that the participant was invited to the survey. If yes, the survey platform approves the PC's access and waits for the participant's mobile device to access the survey. To the PC, a link to the survey platform is shown to assist with the mobile device's access. We can take advantage of a QR code or a shortened URL, for instance.
2. The participant accesses the link with their mobile device. The survey platform then maps the participant's session on the PC and the mobile device.
3. The survey platform begins the survey on the PC. It loads the video clips, captions and sub-captions of the questions in the survey and plays the video clips with the captions. At this time, the participant's mobile device waits for a message from the survey platform.
4. When each video clip ends, on the PC the survey platform shows a sub-caption which explains the meaning of the question shown on the mobile device.
5. The mobile device receives the question from the survey platform. Until the participant replies, the PC waits for a message from the survey platform.
6. If the participant submits an answer through their mobile device, the survey platform stores the answer with the question id of the survey.
7. The survey platform then moves to the next question and jumps to step 3. Once the participant responds to all questions on the survey, he/she is done with the survey.

C. Characteristics of the Survey Method

1) **Virtual:** In existing studies, to assess the participants' experience as regards a PCE, the experimenter needs to make many assumptions about a PCE when preparing the survey infrastructure. Therefore, each survey requires a considerable amount of time and money while also relying on the competence of the experimenter. To prevent problems in this

case, the proposed survey platform provides indirect experience related to the PCE to the participants through the video clips. In addition, a standardized survey method of the proposed survey platform guarantees the same quality of survey result regardless of the experimenter's ability.

2) Interactive: The survey platform interacts with the participants' mobile devices. We assume that a user's personal device stores their private information and interact with other devices/services in the PCE. Because a mobile device is the most familiar and trusted device, the participants may act as they are living in the actual PCE. While watching the video clips during the survey, the participants have to give their privacy approval via their mobile devices. The participants may feel that their decisions affect the scenario of the survey. Therefore, they may reveal accurate private-related behaviors when they are more self-motivated.

3) Open and Sharable: An experimenter gives a survey by uploading their scenarios and questions. However, this work is very difficult for the less-skilled experimenters. In addition, it is difficult to ensure objectivity of the survey. In the survey platform, the experimenter does not need to start from scratch, as he/she can recycle existing surveys. This also helps an experimenter to verify whether the participants in the previous survey were biased or not. Moreover, the experimenter can even utilize the result of an existing survey. The same data allows an objective comparison between the experimenter's privacy model and existing ones.

4) Non-biased: The survey platform is open to the experimenters and does not depend on the content of a scenario. Therefore, the survey method can be applied to a wide variety of scenarios. However, it may contain a scenario that is affected by the experimenter's subjectivity. Nevertheless, other scenarios in the survey platform can reveal bias in the scenario by performing other surveys. If an experimenter selects a scenario written by a third party, the survey may be regarded as a more objective approach. For some future video clips made by professionals at major corporations (e.g., Microsoft, Nokia, and NTT DoCoMo or others), these clips are well represented in a PCE. Also the other experimenters can easily accept these scenarios because these are not typically affected by the experimenter bias.

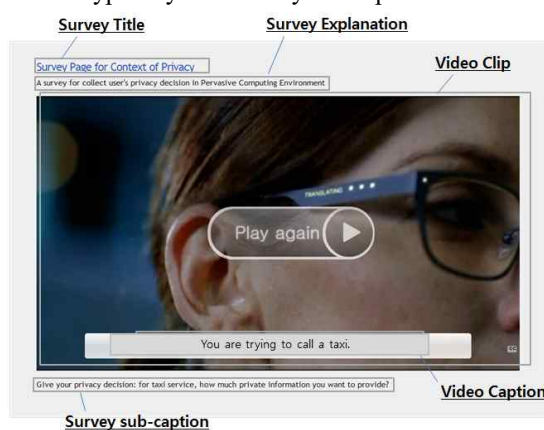


Figure 2. A screenshot of a video clip in the survey platform

V. IMPLEMENTATION

We implemented the survey platform as a web-based platform. We chose the TOMCAT 7 [5] web container to handle the basic session and interlocking, and we implemented each feature in JAVA EE [6]. The database of the survey platform uses MYSQL [7]. Both the running of a video and the triggering of a question to the participants' mobile device take advantage of the open source software JWPLAYER [8]. Because the survey platform interacts with the participants' mobile devices, the implementations of the survey platform can vary depending on the choice of the target specification of the device. However, by choosing common web technology, we can interact with the participants' devices regardless of the specifications. Even if the participant does not have a mobile device, he/she can perform a survey by launching two web-browsers on the PC. In addition, multiple remote participants can simultaneously perform a survey.

A participant watches two different screens; one is a video-clip screen and other is a privacy approval screen. We chose this survey structure to prevent the following concerns. First, if a participant only watches a video clip, the participant may not easily understand what the scene means.

Second, each participant can interpret same video clip in different ways. As a result, it is difficult to assess the actual privacy decisions of the participants in the same context. Therefore, the survey platform provides captions that describe the current situation for the participants so as to maintain the same context. In addition, the survey platform sets a separate instruction space for a sub-caption at the bottom of the PC screen to guide the participants in how they should answer the question when the video clip finishes. Figure 2 shows a video-clip screen.

Figure 3 shows a privacy approval screen. The top of the image shows the brand logo of a taxi company, which is the subject of the service. In addition, the middle of the image is the policy level of the service. The privacy level 'HIGH' denotes a trusted entity. We briefly divide the policy level into 'HIGH/MIDDLE/LOW' because the average participant may find it difficult to interpret a privacy policy. We also put a 'see details' link for advanced participants to review the full policy. The bottom of the image shows the requirements of the privacy information needed by the service provider. According to the image, the taxi company requires the participant's current location and destination. The participants can select the option button for each instance of information after considering their privacy issues.

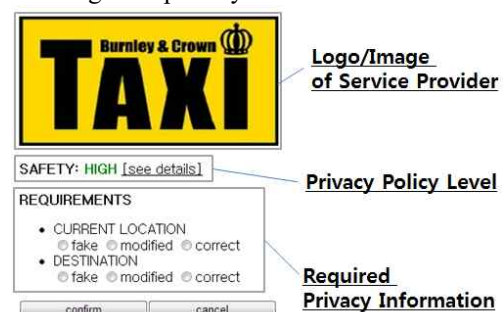


Figure 3. A screenshot of privacy approval in the survey platform

VI. EVALUATION

A. Survey Details

To verify that the proposed survey method more accurately reflects the privacy decisions of the participants, it is necessary to compare the levels of effectiveness between the proposed survey method and an existing paper-based survey. Therefore, in this evaluation, we performed both a paper survey and the proposed survey for the same participants with the same contents. For the paper survey, we used LimeSurvey [9], online open source survey application. We then analyzed the differences and asked the participants what the differences meant. Among 22 participants who took the paper surveys, 18 participants also took the proposed survey. 12(67%) of them were researchers in computer security and 6(33%) were graduate students who study computer engineering. 17(94%) of them were male, and their ages ranged from 24 to 47 (20s:4, 30s:11, 40s:3). They were not compensated in any way.

B. Comparison with a paper-based survey

We chose the scenario 'Productivity Future Vision' (2011) [10] from Microsoft for the evaluation survey. After reviewing the video clip, we extracted the scenes that would require personal information and determined which privacy approval screens will be shown to the participants. From the 11 scenes, a service provider requires personal information from the participants to provide a personalized service. The paper-based survey consists of the same contents, but the context expressed in the video clip does not mention this. Of course, it is possible to present a detailed situation and obtain a privacy decision of the participants, but, as previously noted, this largely depends on the competence of the experimenter. Therefore, we decided to exclude the context information in the paper-based survey.

TABLE 1. PRIVACY CONCERNS OF THE PARTICIPANTS
(1:EXTREMELY HIGH, 3: MIDDLE, 5: EXTREMELY LOW)

Item \ Concerns	Average	Standard Deviation
Overall Privacy	2.55	0.96
Payment	1.59	0.59
Work	2.14	0.94
Photo	2.14	1.04
Location	2.45	1.06
Trip/Lodge	2.45	1.10
Name	3.18	1.18
Interests	3.45	1.26
Favorite Food	4.32	0.84

TABLE 2. PRIVACY DECISIONS OF THE PARTICIPANTS BY PAPER SURVEY
(1:EXTREMELY HIGH, 3: MIDDLE, 5: EXTREMELY LOW, GRAY: +1 STANDARD DEVIATION)

Item \ Service	Location	Lodge	Photo	Name	Interest	Payment	Work	Food
Transport	3.09	2.95	1.59	1.91	2.64	1.73	1.64	2.95
Map	3.59	3.14	1.68	1.77	2.68	1.55	1.45	3.14
Lodge	3.41	3.5	1.82	2.36	2.55	2.18	1.59	3.14
Donation	1.91	1.73	1.55	2.27	2.18	1.86	1.41	2.05
Coworker	2.91	2.55	2.91	3.77	3.27	1.73	4.14	3.09
Business Partner	2.41	1.86	2.77	3.59	2.59	1.68	3.55	2.64
Family	3.64	3.86	4.18	4.36	3.68	3.36	2.82	4.38
Average	2.99	2.79	2.35	2.86	2.79	2.01	2.37	3.05

TABLE 3. PRIVACY DECISIONS OF THE PARTICIPANTS BY PROPOSED SURVEY (1:EXTREMELY HIGH, 3: MIDDLE, 5: EXTREMELY LOW, GRAY: +1 STANDARD DEVIATION)

Item \ Service	Location	Lodge	Photo	Name	Interest	Payment	Work	Food
Transport	4.36	3.77	n.a	n.a	n.a	n.a	n.a	n.a
Map	4	n.a	n.a	n.a	n.a	n.a	n.a	3.94
Lodge	4.35	4.82	3.35	3.52	3.88	n.a	n.a	n.a
Donation	n.a	n.a	n.a	2.23	n.a	2.23	n.a	n.a
Coworker	n.a	n.a	n.a	n.a	n.a	n.a	4.47	n.a
Business Partner	n.a	n.a	n.a	n.a	n.a	n.a	3.70	n.a
Family	n.a	n.a	n.a	n.a	4.88	n.a	n.a	n.a

Table 1 and 2 show the results of the paper-based survey. Table 1 shows privacy concerns of the participants. We can identify that they worry about their privacy relatively high except 'Favorited Food'. However, in Table 2, the participants show different decisions. They gave more generous decisions normalized to middle concerns. Although last-three items in Table 1 show relatively low privacy concerns, the participants show more concern to these items in Table 2.

Figure 4 shows the difference of privacy decision between the proposed survey method and a paper-based survey method. For almost items, the participants respond with higher value. The difference gap is significant except some items (donation and work). We can assume that the participants have clear criterion for these items regardless the environments.

For each participant, by comparing the results of each survey in Tables 2 and 3, we found differences amounting to 28% (average differences: 1.45, standard deviation: 1.07). After both survey, we also asked which survey method revealed more accurate privacy decisions of the participants. The participants answered that the proposed survey is easier and reflect more accurate privacy decision. Although the participants had experienced the proposed survey for the first time, they felt it is easier than the paper-based survey. Table 4 shows the details.

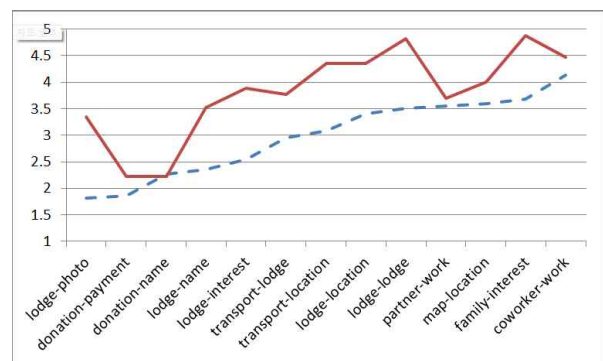


Figure 4. Different privacy decisions between two survey methods (solid line: proposed survey, dotted line: a paper-based survey)

TABLE 4. EVALUATIONS OF THE PROPOSED SURVEY METHOD
(1:EXTREMELY LOW, 3: MIDDLE, 5: EXTREMELY HIGH)

Questions	Answers	Deviations
Easier than a paper-based survey	4	1.07
Show actual PCE	4.53	0.51
Collect more accurate privacy decision than a paper survey	4.26	0.69

VII. DISCUSSIONS

The proposed survey presents a specific scenario of PCE to reveal more accurate privacy decisions of the participants. According to Table 1 and 2, people tend to more conservative in privacy. When people want to serve a service in PCE, however, they have to provide their privacy information more often. The tendency was shown in Table 3. In addition, they respond that the proposed survey method shows real PCE and collects more accurate privacy decisions than a paper-based survey in Table 4.

In previous works, to evaluate the proposed privacy model, an experimenter had to design a survey scenario and implement every comparable privacy model. Moreover, they had to arrange a physical experimental site and invite participants. These survey procedures make the process difficult, and the survey results cannot guarantee objectivity. With the proposed survey platform, however, the experimenters can easily evaluate their privacy models. Users can also compare their privacy models with other privacy models simply with existing survey results.

We should consider ways to activate the participants. The participants assume that they are only involved in the current survey. Therefore, it can be difficult to ask them to take another survey again. Hence, we should provide some benefit to the participants. The participants can observe their privacy decisions while performing the surveys repeatedly. Moreover, they can objectively confirm a privacy modeling technique which suits them. Because earlier work [2] found that the concerns of a user are not related to the actions of the user, the proposed survey method helps the participants in terms of user education.

Privacy and security measures are also required in the survey platform. The participants may feel reluctant to utilize their data in other studies. The survey platform should notice that the results are used anonymously and convert the identifiable information in the results to n-bits hash before sharing it with another party.

VIII. CONCLUSIONS & FUTURE WORKS

Several studies have proposed privacy models for PCEs. However, these previous works had not been verified publicly as to whether their privacy models express users' actual privacy behaviors feasibly. Although previous works ran a survey or experiments, it is difficult to verify the results because they did not provide sufficient details about the survey. Also, experimenter bias may affect the results of those surveys.

In this paper, we propose an open online interactive survey platform that allows a user to experience a virtual PCE. With the survey platform, the experimenters and the participants can overcome the constraints of time and place through an online approach. Whenever and wherever, the survey platform can collect a participant's privacy decisions by interacting with the participant's mobile device. Because the survey platform can share the survey environments and even the results with the other researchers, researchers can easily compare and analyze the performances between the privacy

models. In the evaluation, we show that the proposed survey method reflects the user's privacy decisions 28% better than the existing paper survey method.

Future researcher will proceed as follows. First, we will enhance the proposed survey platform by running more surveys with various scenarios and other participants. Second, we have to try actual research that presents a new privacy model via the proposed survey platform. Doing so will verify that the proposed survey platform is easy to use for a survey, and it can validate the privacy model. Third, we should improve the proposed survey platform to cover a wide range of research cases by sharing the survey with other researchers.

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